NASA-CR-192243

G-91
277778

N93-71546

(NASA-CR-192243) STUDIES OF REGIONAL AND GLOBAL TECTONICS AND THE ROTATION OF THE EARTH USING VERY-LONG-BASELINE INTERFEROMETRY Semiannual Status Report, 1 Nov. 1989 - 30 Apr. 1990 (Harvard Coll. Observatory) 10 p

Unclas

Z9/46 0146930

Semiannual Status Report

for the period 89/11/1 through 90/4/30

on

Grant NAG 5-538

Studies of Regional and Global Tectonics and the Rotation of the Earth Using Very-Long-Baseline Interferometry

Prepared by J.L. Davis and T.A. Herring

Irwin I. Shapiro
Principal Investigator

Harvard College Observatory
60 Garden Street
Cambridge, Massachusetts 02138

Reference: Grant NAG 5-538
Subject: Semiannual Status Report for 89/11/1 through 90/4/30

Progress

Atmospheric delay studies

Previous to this report period, we had investigated modeling variations in the equivalent zenith wet delay determined from water-vapor radiometer (WVR) data obtained at Onsala, Sweden. These variations were azimuth- and elevation-dependent, and could be as large as 10–20 mm over very short time periods (a few minutes). We had found that these variations could be well described by

$$\tau^z(\epsilon,\phi,t) = \tau^z_\circ + \vec{\Gamma}\cdot\vec{x} + \dot{\vec{\Gamma}}\cdot\vec{x}\Delta t + \upsilon\Delta t \tag{1}$$

where $\tau^z(\epsilon,\phi,t)$ is the equivalent zenith wet delay (*i.e.*, the wet delay "mapped" to zenith) measured by the WVR in the direction of elevation angle ϵ and azimuth ϕ at time t; $\tau^z_\circ$ is the equivalent zenith wet delay at time $t = t_\circ$; $\vec{\Gamma}$ is the horizontal zenith delay gradient; $\vec{x}$ is the horizontal vector from the WVR to the sub-layer point (see below); $\dot{\vec{\Gamma}}$ is the time derivative of the horizontal zenith-delay gradient; $\Delta t = t - t_\circ$; and υ is the time derivative of the zenith delay for $\vec{x} = 0$. In (1), the variation in zenith delay has been modeled as an infinitely thin layer a height H above the (flat) earth. The sublayer vector $\vec{x}$ is therefore

$$\begin{aligned} x_n &= H\cos\phi\cot\epsilon \\ x_e &= H\sin\phi\cot\epsilon \end{aligned} \tag{2}$$

In (2), x_n is the north component of $\vec{x}$, and x_e is the east component.

The model described in (1) has six parameters to be estimated: $\tau^z_\circ$, υ, and two components each for $\vec{\Gamma}$ and $\dot{\vec{\Gamma}}$. We have taken H to be 1 km, since we would expect the gradient layer to be found within the planetary boundary layer. (The value of the parameter H merely scales our estimated value of the gradient and gradient-rate.)

Previous to this report, we had found that, after estimation of the six free parameters, (1) describes our WVR data extremely well, yielding weighted root-mean-square (WRMS) post-fit residuals of about 1 mm (Fig. 1). Approximately 20–30 minutes of WVR data were used for each of these solutions, yielding 60–90 observations per solution.

During the time period of this report, we attempted to place the *ad hoc* mathematical model in (1) on a more physical footing. The model in (1) was developed by starting with a simple time-independent gradient model, represented by the first two terms in (1), and then adding the terms which seemed needed, based upon examination of the post-fit residuals. The model in (1) is a second-order Taylor expansion, in both time and distance from the WVR, of the equivalent zenith wet delay, with some of the terms (somewhat arbitrarily) removed. Furthermore, (1) does not obey the frozen-flow hypothesis, which states that turbulence is "frozen" as it advects past a site. The mathematical statement of this hypothesis is

$$\vec{V} \cdot \vec{\nabla} \tau^z + \frac{\partial \tau^z}{\partial t} = 0 \tag{3}$$

where $\vec{V}$ is the mean wind velocity. The full second-order expansion for the zenith wet delay which obeys (3) is

$$\tau^z = \tau_\circ^z + \vec{\Gamma} \cdot (\vec{x} - \vec{V}\Delta t) + (\vec{x} - \vec{V}\Delta t) \cdot \vec{\vec{\Upsilon}} \cdot (\vec{x} - \vec{V}\Delta t) \tag{4}$$

where $\vec{\vec{\Upsilon}}$ is the second-derivative tensor for the zenith delay, *i.e.*,

$$\Upsilon_{ij} = \Upsilon_{ji} = \left. \frac{\partial^2 \tau^z}{\partial x_i \partial x_j} \right|_{\substack{\vec{x}=0 \\ t=0}} \tag{5}$$

The model described by (4) has eight free parameters: $\tau_\circ^z$, two components of the gradient, three independent components of the second-derivative tensor, and the two components of the mean velocity. However, (4) is nonlinear in these parameters. Adequate separation of the various parameters is achieved only for very long time periods. Unfortunately, the model (4) breaks down somewhere between 30 and 60 minutes, as the random atmospheric fluctuations begin to dominate the fit. Therefore, instead of going to more complicated models, we will continue to use (1), and to use time spans of 20–30 minutes to estimate the parameters.

We will continue to investigate our model for horizontal variations of the wet delay. Our immediate goal is to investigate the general applicability of (1). We will therefore be continuing to attempt to understand the physical basis for (1), and to use more WVR data, both from the Onsala site and from other sites. Our long-term goal is to develop a wet-delay "mapping function" for use in calibrating WVR's and to map WVR-determined wet delays to elevation angles and azimuths where the WVR did not actually observe.

Analysis of VLBI "Extended R & D" experiment

We have completed a preliminary analysis of the Extended R&D experiment carried out in October, 1989. For this analysis, a new hydrostatic delay mapping function was developed to overcome the relatively large errors in the CfA-2.2 mapping function for observations made below 5° elevation angle. (Because CfA-2.2 was designed for elevation angles above 5°, there can exist differences of up to 80 cm between raytrace and CfA-2.2 at 3°.) This new mapping function has been sent to GSFC for testing along with the Lanyi model. We have examined the repeatability of the estimates for both baseline length and station coordinates from this data set. The baseline repeatability as a function of baseline length is shown in Fig. 2 for elevation angle cutoffs of 3°, 5° and 7°. There is currently some improvement in the results when data below 5° are excluded from the analysis. However, we have not yet calculated the formal significance of the differences. Since the addition of atmospheric profile data to the analysis should improve the mapping functions, it is premature to conclude anything about the utility of the data below 5°. We have also studied the coordinates of the Pietown antenna in a coordinate system determined by Westford, Mojave, and Fairbanks. These results are shown in Figs. 3 and 4. Here we show results for the new mapping function (squares) and CfA-2.2 with the data below 5° not used. For both the horizontal and vertical coordinates, the results with the two mapping functions look very similar. We are continuing the analysis of these data. In particular, the use of the radiosonde data in the mapping function will be the next major task.

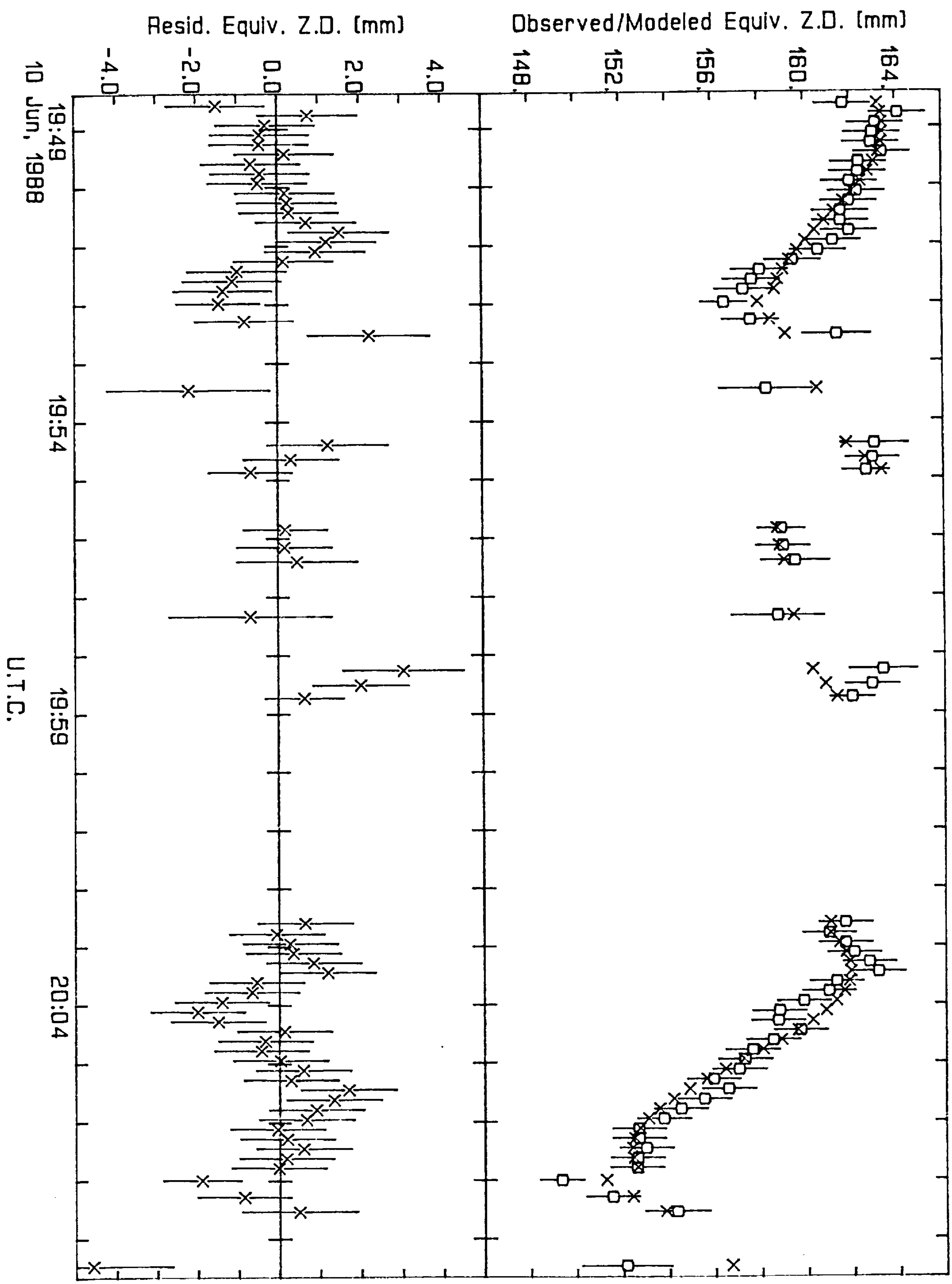
Figure Captions

Figure 1. (a) Plot of observed equivalent zenith wet delays (circles with error bars) and postfit model values (X's), for the model described in (1). (b) Postfit residuals.

Figure 2. Baseline length repeatability for the 12 sessions in the Extended R&D experiment.

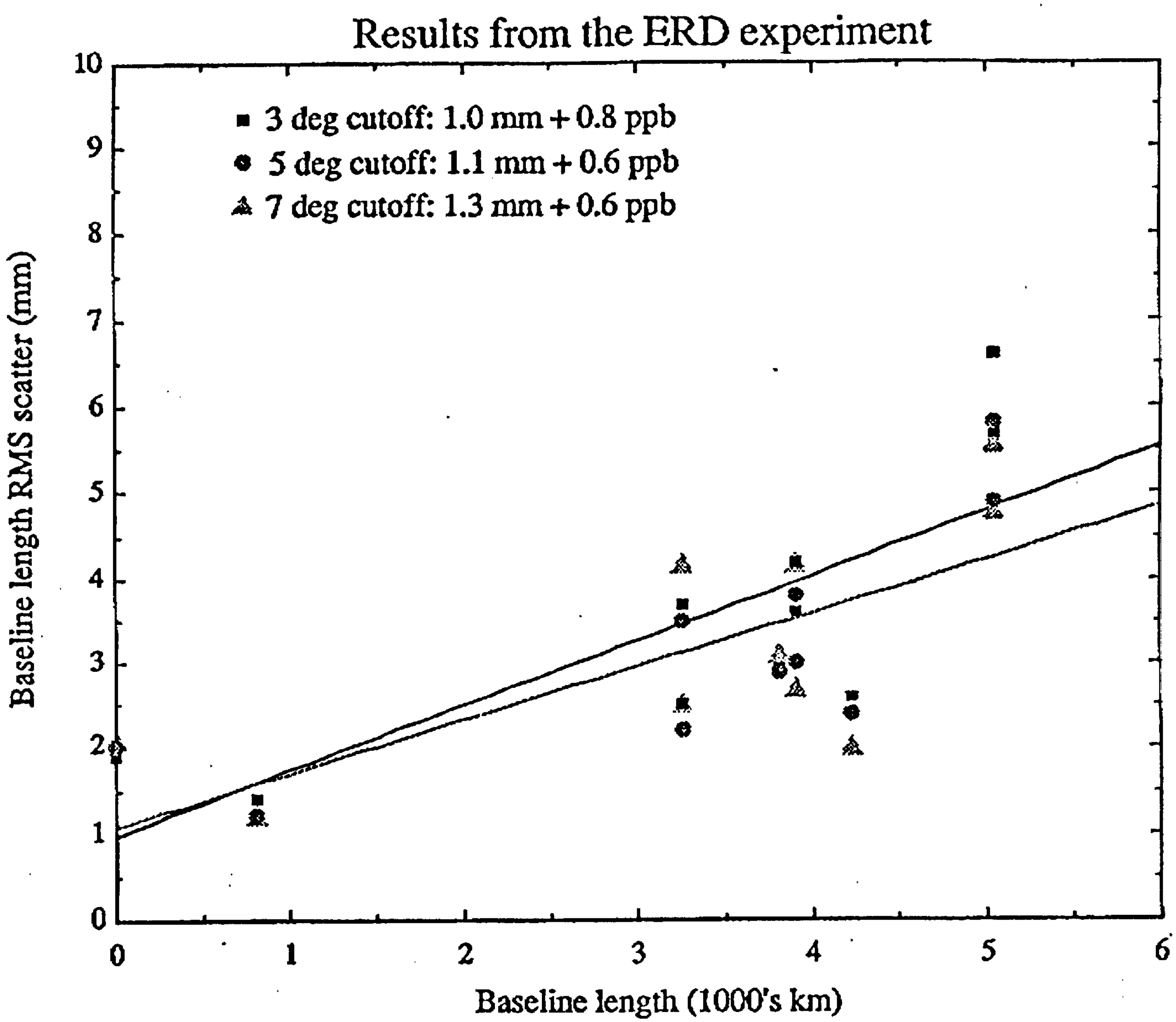
Figure 3. Estimates of the North and East components of the Pietown antenna in a coordinate system defined by Westford, Mojave and Fairbanks. Results for the new mapping function, discussed in the text, and the CfA-2.2 mapping function with data below 5° excluded from the analysis.

Figure 4. Estimates of the height of Pietown (see Figure 3 caption for details).



Resid. Equiv. Z.D. (mm)
Observed/Modeled Equiv. Z.D. (mm)
-4.0
-2.0
0.0
2.0
4.0
148.
152.
156.
160.
164.
19:49
10 Jun, 1988
19:54
19:59
20:04
U.T.C.

Fig 1



Results from the ERD experiment
3 deg cutoff: 1.0 mm + 0.8 ppb
5 deg cutoff: 1.1 mm + 0.6 ppb
7 deg cutoff: 1.3 mm + 0.6 ppb
Baseline length RMS scatter (mm)
Baseline length (1000's km)
0
1
2
3
4
5
6
7
8
9
10

Fig 2

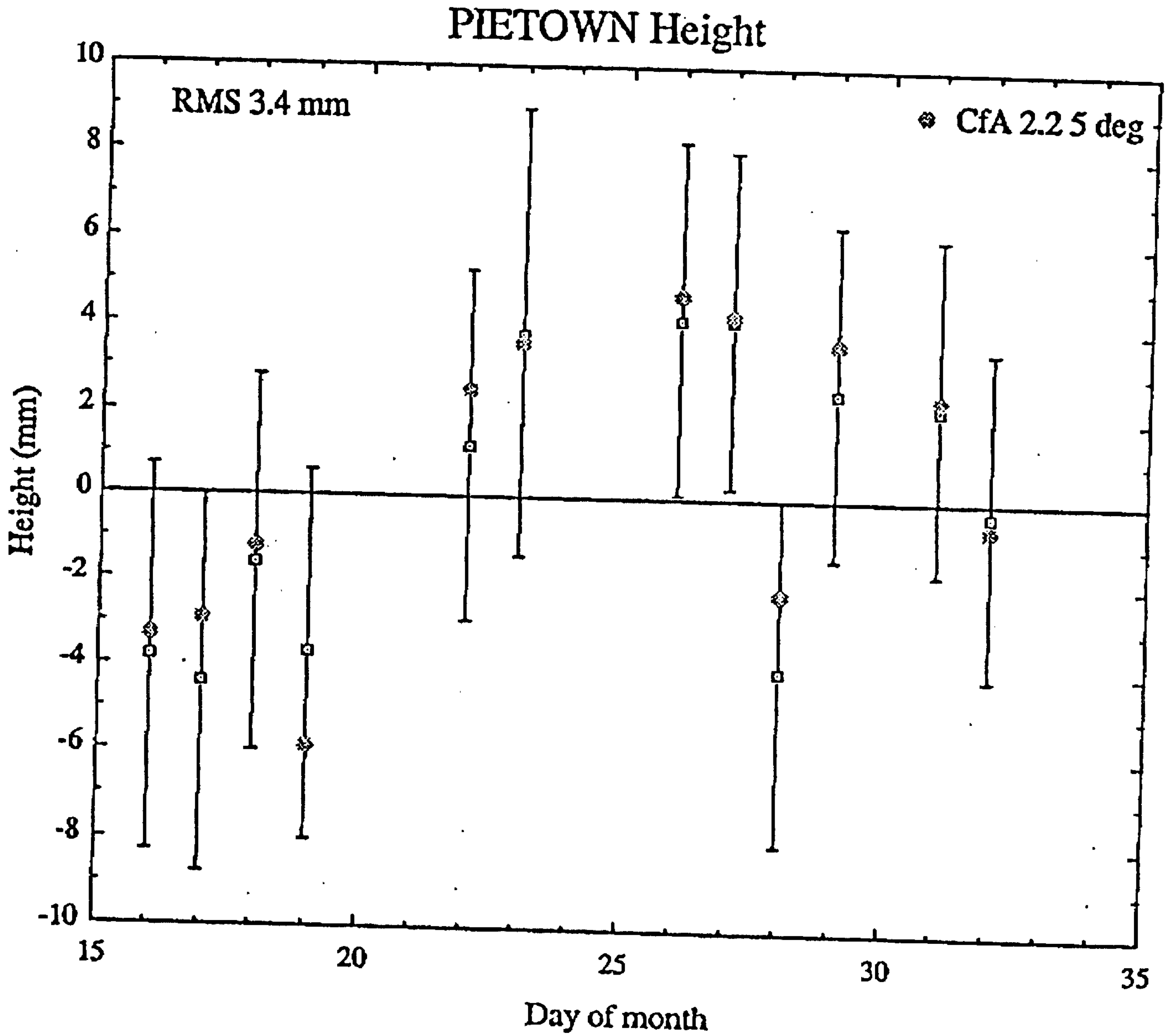

PIETOWN Height
RMS 3.4 mm
CfA 2.2 5 deg
Height (mm)
10
8
6
4
2
0
-2
-4
-6
-8
-10
15
20
25
30
35
Day of month

Fig 3

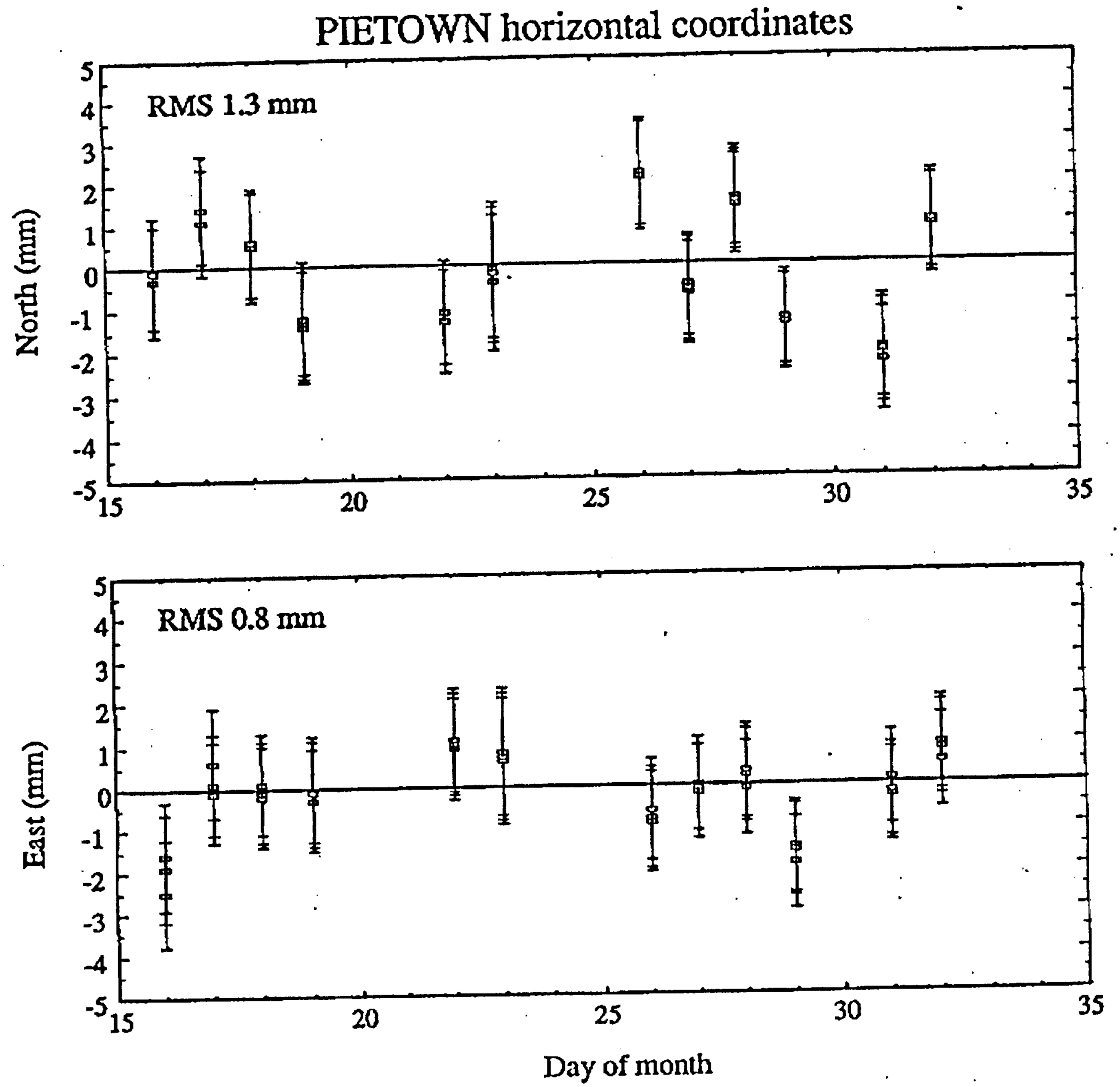

PIETOWN horizontal coordinates
RMS 1.3 mm
North (mm)
RMS 0.8 mm
East (mm)
Day of month

Fig 4